

## Nova Note # 1105

# Bookends and Buckling Insurance for the Far Detector

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### *Abstract*

We take a global look at the assembled NOVA far detector, with one and with both bookends in place.

We address consequences of

Thermal expansion;

Block leaning;

Collective block leaning;

Block buckling;

Collective block buckling;

and propose an inexpensive “Insurance” scheme against block buckling

### Introduction

The NOVA far detector, as examined here, consist of 46 blocks of 31 planes of extrusions each, with a total mass of 20 ktons.

The horizontal extrusions have 3 mm thick outer skins and 2mm webs; the vertical extrusions have 4.5 mm outer skins and 3 mm webs.

The planes are 15.7 m wide and 15,7 m high.

The blocks are spaced at the bottom by ½” thick spacer boards, and connected at the top by a connector board ½” thick, 6” high, of full width, which is glued to both blocks.

### Thermal Expansion

We examine here the behavior of a completed far detector when its temperature changes by 10 C, for the one- and two-bookend case.

#### *One Bookend Case*

For a TCE of 72.8 ppm per degree C (literature average) and a 10 C temperature increase, the far detector length grows by 4.8 cm.

Starting with perfectly vertical blocks at the reference temperature, and a single bookend, blocks will begin to lean away from the bookend.

The connector boards tie all block tops together.

#### **There is an added effect:**

As the blocks lean more and more, their center of gravity (CG) moves off center, adding forces and deflections.

For a detector starting with a perfectly vertical first block at the bookend, the last block leans by 4.8 cm from thermal expansion alone, which increases to 5.5 cm from the additional gravity loading.

As an aside, the smallish gravitational boost factor reassures us that the full detector is stable against collective leaning of blocks in the middle, far away from the book ends, even without relying on the buckling stability of each block.  
The bookend resists the collective leaning force of 172,000 N ( 38,500 # force, 17.5 ton)  
.The first connector board sees a modest glue stress of 9 psi.

### ***Two Bookend Case***

We assume two unyielding bookends.

The first and last block are glued to their respective bookends by connector boards.

Upon raising the temperature by 10 C, none of the blocks move.

However, pressure builds up at the connector panel location to resist the thermal expansion.

We calculate the spring constant of a block under the following assumptions:

--the elastic modulus of PVC is 500 ksi

--only the webs compress

--the top 12 inches of the modules participate (i.e. twice the height of the connector boards)

We find a spring constant of one block of  $4.93 \times 10^8$  N/m.

The whole detector has a spring constant of  $1.07 \times 10^7$  N/m.

The thermal expansion of 4.8 cm creates a force in the connector boards of 257,000 N (57,641 #force, 26.2 ton). This force must be resisted by the tops of each bookend.

The stress in the webs of the horizontal extrusions is 159 psi. Ang Lee's note # 957 concludes that the webs can resist a stress of 500 psi with a safety factor of 4.4 against buckling. The average pressure at the top board area is only 7.8 psi.

### **Block leaning**

We examine the forces resulting from a single block leaning, i.e. not being exactly vertical, and the case where all blocks lean in the same direction.

For a block leaning by an offset D at the top, the horizontal force component will be  
Horizontal force =  $m g D / 2 H$ ,

Where m is the block mass, g the earth acceleration, and H the total block height.

For a displacement D of 2.54 cm, the horizontal force is 1,730 N (=389 #)

If all blocks were leaning by the same amount, the total force would be 8.1 tons, augmented by a small amount due to the extra gravitational boost. This is about half the force we found for a 10 C temperature change. The force itself poses no problem, but may promote or accelerate block buckling as it creates a non-zero bending moment on the blocks..

### **Block Buckling**

Ang Lee has concluded, in DocDB note # 826, that the NOVA structure will have a safety factor of only 2.1 against block buckling if the modulus of PVC falls to 150 ksi due to creep:

**Table 2 Stress and Stability for 31 planes Block Assembly**  
**E=0.15e6 psi ; Scallop backside**

<b>Wall thickness</b>	<b>Maximum Stress (psi)</b> Near the bottom	<b>Deflection</b> along the beam direction (inch)	<b>SF</b> (global buckling _ after 20 years)	<b>Adhesive stress</b> (psi)
4.5/3 mm for both Vertical and Horizontal	< 700	0.051	4.4	230 Too high!
<u>Current base line</u> 4.5/3 mm for vertical 3/2 mm for the horizontal	< 700	0.054	2.1 Low!	175

Ang suggests as possible remedies to increase the wall thickness of the horizontal modules to the same value (3mm, 4.5 mm) as the vertical modules in the current design. This will add inert material and increase the cost of the detector. It would be desirable to stay with the present design, if that can be accomplished with acceptable assurance of performance of the structure. **This note proposes a solution.**

We examine the simplest buckling shape, that of blocks simply connected at top and bottom, and assuming a shape of uniform curvature. The purpose is to get a sense of the forces needed to counteract the buckling forces. This can, of course, be refined with FEA calculations as warranted.

In this simple model, the CG height changes as

$$\Delta = \frac{4}{3} * \frac{b^2}{H}$$

Where b is the maximum displacement (bow) , at half height,

And H is the full detector height.

The horizontal force is the derivative

$$d(\Delta)/d(b) = \frac{4}{3} * \frac{2b}{H}.$$

For a bow of 1.27 cm we get a force of 9247 N (2074 # force) .

If all 46 blocks were to buckle the same way, the total force needed to resist that buckling would be 94,930 # force = 43.2 ton force.

This force would need to be applied at half height, hence would be not too different from the 17.5 ton force from thermal compression at 10 C, which acts on the top of the bookends.

## **Buckling and Buckling Insurance**

### ***Gap Filling Schemes***

Proposals have been made (DocDB document 957 by Ang Lee and # 1050-v2 by Vic Guarino) to fill the gaps between blocks after the second bookend is in place.

This proposal has attractive features:

--it prevents the buckling of blocks

--it stops the swelling of cells due to creep (although Ang Lee's note DocDB # 855 addresses this issue and concludes that the cells are safe against creep failure).

More detailed work will be needed to address some concerns with the scheme:

#### ***a. Web Buckling***

The full hydrostatic pressure must be supported by the 2 mm thick webs of the horizontal extrusions. The resulting stress is 360 psi. Ang Lee calculated in DocDB Note # 957 that, even with a 10" tear in a horizontal web, the maximum stress is only 500 psi, and the safety factor against horizontal web buckling is 4.4, which seems adequate.

#### ***b. Forces on the bulkheads***

After filling, and due to creep stress relaxation, eventually the full hydrostatic pressure needs to be resisted by the bookends.

This results in a triangular pressure distribution with a base of 20 psi.

The resulting force is 3133 ton, applied at 1/3 the detector height.

This is 50 times larger than typical forces for when gaps are not filled.

#### ***c. Foam Installation***

Foam installation may be difficult.

I imagine one would need to use something like 50 ft long plastic hoses that fit into the half inch gap. The hoses can only be controlled in elevation, since no side forces can be applied. The installer would need to start generating foam at the bottom and pull the hose up as the gap fills. There would be no visual feedback to the installer.

I have played today with "Great Stuff" foam, and found that it spreads sideways from the nozzle for about 6 to 12 inches, no more. This foam is different, though, from what we would be using.

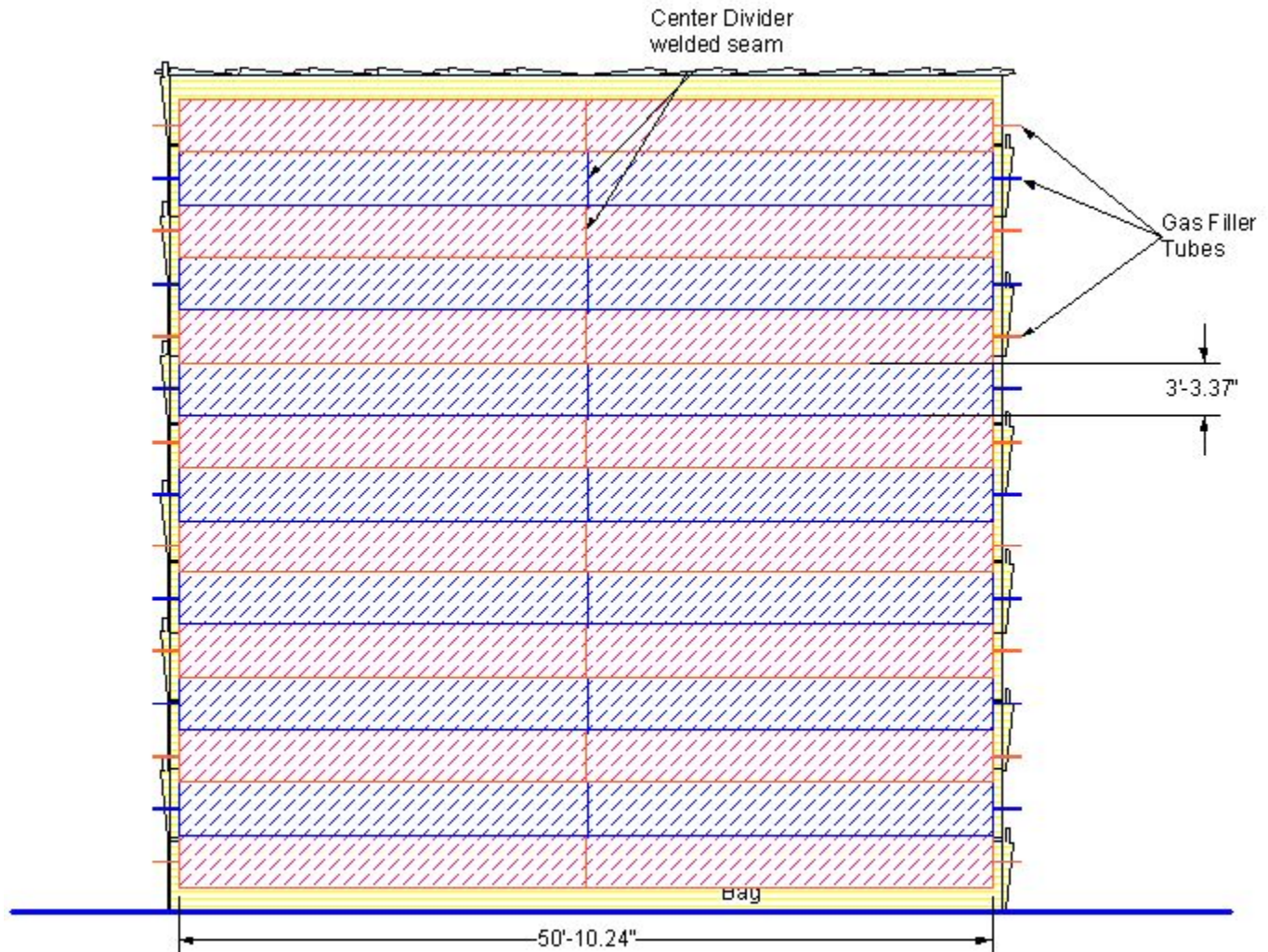
For the NOVA job we would need to use a binary foam formula that is dispensed through a mixing nozzle. Fermilab used to have such a machine at the shipping office, for packaging. They removed it recently, allegedly due to concern about "toxic chemicals

#### *d. Foam uniformity*

It will be difficult to assure that there are no large (over 0.5 m, say) void areas caused by uneven installation. Such void areas can induce stress concentrations at their edges once the hydrostatic pressure has reached equilibrium with the foam.

I have also seen large variations in foam bubble size and compliance within the same foam structure. This is not a problem for weather sealing or floatation applications but can introduce undesirable stress patterns in our application.

#### *The Scheme*



**NOVA Block Buckling Insurance Bags**

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At the face of each block, while it is still lying on the assembly table, we would install a set of polyethylene bags that cover the whole 15m x 15 m face.

The bags might be each 1 m high by 15 m wide. They can be made from endless tubular sleeve stock.

They would be attached with double-sticky tape, e.g. the very tenacious “carpet tape” along their top edge.

Each bag would be divided into two horizontal volumes, each 1 m high by 7.5 m wide, by welding a seam across the bag.

Each end would have a filling tube welded on for connecting to an air line for pressure control.

### ***How does it Work ?***

Assume that one of the blocks begins to buckle after some time.

We have calculated the force to resist the buckling-induced horizontal force above.

The example was a force of 2074 #force for a buckling deflection of 1.27 cm at half block height..

To stop the buckling from growing, one would resist this force by inflating, say, the middle 7 bags to a pressure of 0.01 psi (= 0.34 inches water pressure) . One might also choose to double that pressure to bring the block slowly back to a good posture.

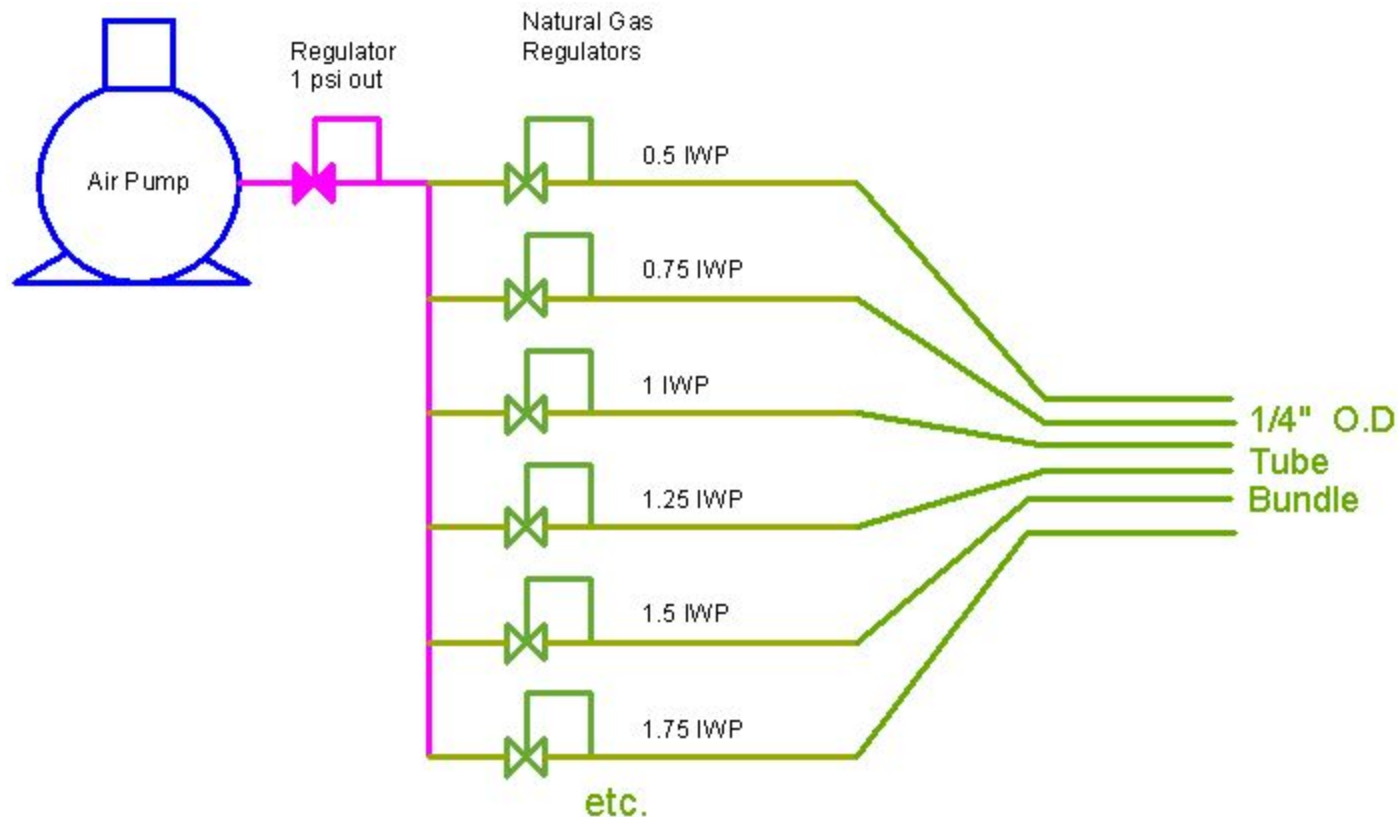
The same force pushes, of course, against the neighbor of the buckled block, which is not desirable. Therefore we need to add the same pressure to all bags between the afflicted block and the bookend at the convex side of the block.

Since this is a linear system (defined as a system where all forces are additive), it is easy to calculate a pressure pattern for all bags that deals with an existing complex buckling picture.

### ***Isn't that quite Complicated?***

It is useful to keep in mind that for reasonably leak-free bags, a small air supply line (e.g. 1/4" OD) can keep all bags pressurized that are tapping into it, at the same pressure.

One can imagine a bundle of 12 or 24 plastic tubes running along the experiment on both sides, each carrying a slightly different air pressure. The pressure can come from a very small air pump and a set of “natural gas” type pressure regulators, that are designed for very low pressures, are inexpensive, and ultra-reliable.



## Bag Pressure Generation and Distribution

When a bag needs to be connected one cuts the 1/4" plastic line, installs a quick-clamp Tee, and connects to the bag's filler tube. No need to shut off the pressure for that.

### ***Atmospheric pressure effects***

Changes in atmospheric pressure have no effect.

The pressure regulators set the gage pressure with reference to the prevailing atmospheric pressure and the air pressure acts uniformly around modules.

The required pressure values are quite small, comparable to the pressure difference (15mm WP) between the bottom and top elevation of the detector. It turns out that the local bag overpressure is independent of the elevation of the pressure regulator and of the bag elevation if air is used in the system.

### ***How can we tell if a block is buckling?***

The simplest way might be to hang a plumb bob along each gap, on both sides, for a total of about 90 plumb bobs. Standing on the walkway one should be able to check, once a month or so, for gaps that are no longer lined up with the plumb bob's string (which could be day-glow colored). More sophisticated methods are, no doubt, possible.

### ***Bag Performance***

As shown above, the required pressure are way below one psi.

I have looked at the pressure capabilities of PE bags.

Some sources cite the PE yield stress as 3000 psi at 300% elongation.

ASTM D 1998 - 97 "Standard Specifications for Polyethylene Upright Storage Tanks" specifies a design hoop stress of 600 psi at 100F.

A polyethylene bag of 6 mil wall, captured in a half inch gap, can resist an internal gas pressure of  $(600 \text{ psi}) * (6 \text{ mil wall}) / (247 \text{ mil bend radius}) = 14.5 \text{ psi}$

I have tested a 6 mil wall PE bag between two sturdy Al plates spaced by ½ inch, and observed no failure up to 20 psi gas pressure. My test pressure was limited by a poor connection to the filler tube.

### **Conclusions**

We have looked at the behavior of the NOVA far detector with one and two bookends, and calculated the effects of temperature change and leaning blocks. No big problems were identified.

We find significant problems with the two-bookend scenario and filled gaps.

Issues include the difficulty of installing gap fillers, and the very large forces that will develop on both book ends.

We have looked at the buckling of single and multiple blocks.

The low calculated safety factor against buckling is rather low (2.1).

We propose a simple and inexpensive "buckling Insurance" method.